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THE STUDY OF BURNING CHARACTERISTICS OF AP/HTPB/AL BASIC COMPONENTS OF A COMPOSITE PROPELLANT

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ABSTRACT

Starting the research on a solid propellant would be very much easier if the burning characteristics of a simple propellant is known. A simple propellant is a propellant made of three basic components namely oxidizer, fuel and binder without any additive substance to alter its characteristics. Unfortunately, a very limited number of references were published discussing the burning characteristics of simple propellant. This paper describes the burning characteristics of basic formulations of Ammonium perchlorate based propellant. Thirteen sets of propellant formulations have been selected and manually prepared without adding any additives. The simple propellant consists of Ammonium Perchlorate (AP) as an oxidizer, Aluminum (Al) as fuel and Hydroxy-Terminated Polybutadiene (HTPB) as fuel and binder. For each mixture, HTPB binder was fixed at 15% and cured with Isophorone isocyanate (IPDI). By varying AP and Al, the effect of oxidizer- fuel (O/F) ratio on the whole propellant can be determined. The propellant strands were manufactured using press-moulding method and burnt in strand burner at ambient pressure to obtain the initial burning characteristics. Then, four propellant compositions namely p60, p66, p74 and p80 were selected for further evaluation over a range of pressures from 1atm to 31atm. The results show that the increasing of O/F ratio and combustion pressure lead to increase in burning rate. The highest burning rate achieved is 12mmsec^{-1}at combustion pressure of 31atm for propellant p80 which has O/F ratio of 4.0.

Keywords: Ammonium perchlorate, HTPB, aluminium, composite propellant, oxidizer-fuel mixture ratio, chamber pressure and burning rate.

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INTRODUCTION

Generally, a typical composite propellant used in solid rocket motors consists of organic polymeric binder, solid oxidizer, metal powder, curing agent, plasticizer, anti-oxidant and burning rate catalyst. Nowadays, almost all of the latest composite propellants use additives in their propellant in order to enhance the mechanical properties of the propellant. A small amount of additives, which is around 0.5% to 4.67% [1-2] are added in composite propellants for many purposes, such as altering burning rate, improving physical properties, aging characteristics and rheology of the propellant. Although it was reported by Meyer [3] that this small quantity of additives does not affect the performance (i.e. specific impulse, I_{sp}) of the propellant, one cannot help to ask that without the additives what would be the actual burning characteristics of the propellant. Literature search by the author has found that a very limited number of references discussed the characteristics of a propellant without any additives. It is though that the information on the characteristics of a simple propellant without any additives substance such as discussed in the paper will be helpful for those starting the propellant research.

The current study was based on a typical and establishes solid composite propellant, without the additives and composed of ammonium perchlorate (AP) as an oxidizer, aluminium (Al) as a metal fuel and hydroxyl terminated polybutadiene (HTPB) as a binder. Isophorone diisocyanate (IPDI) was used as a cross-linker to cure HTPB and was chosen because of its higher pot life [4]. In this experiment, the strand burner was used to obtain the burning characteristic due to its simplicity, convenience, and cost effectiveness

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[5]. The burning rates were evaluated within the pressure range of 1atm to 31atm. The objective of this work is to evaluate the burning characteristic of AP/HTPB/Al without any additives to get the data where the others can be building on. The scope included measuring burning rate while varying the O/F and increasing chamber pressure using strand burner.

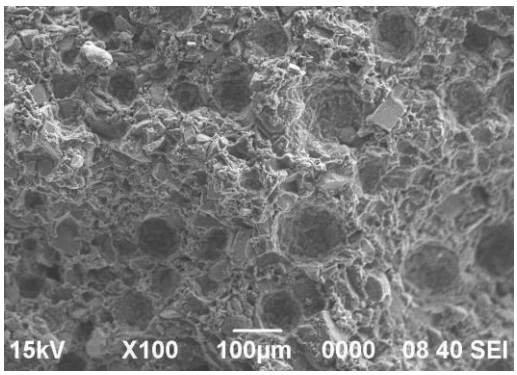
MATERIALS AND METHODS

Propellant Selection Composition

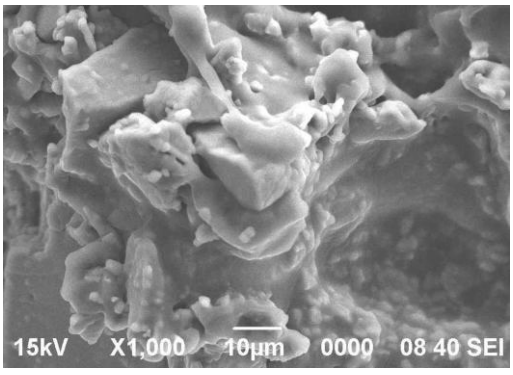
The I_{sp} is the most important performance parameter of propellants. Generally, high I_{sp} is required to obtain optimum performance of a propellant. In this paper, the theoretical I_{sp} was estimated using NASA CEC71 program [6], a computer program for rocket performance. The same program was also applied by several researchers [7-11] to estimates the performance characteristics of AP/HTPB based propellant. According to the theoretical estimations, the I_{sp} of an AP based composite propellant increases with the increasing of AP content and the maximum value is obtained at oxidizer-fuel mixture ratio (O/F) of 90/10 and this is also mentioned by Meyer [3]. However, due to the poor processibility and mechanical properties of the propellant formulation with higher oxidizer loading fraction than 80% [12-13] and reduced I_{sp} for propellant with lower O/F than 60%, the range of composition tested was limited within the range of O/F from 60/40 to 80/20. The percentage of binder was set constant for every mixture in order to find the effect of different O/F ratio to the burning rate.

Propellant Preparation

All of the propellants were manufactured manually in the UTM Propulsion Laboratory. To ensure safe practise, all propellant were prepared in 100gram batches. The first step in mixing process is to produce the binder by mixing HTPB with IPDI accordingly. The ingredients were mixed together using a glass stirring rod in an agitating and swirling motion, similar to the method reported by Matthew Stephens *et al*.[14]. Aluminium was then added to the binder and blended together until all the aluminium powder was coated by the binder. Next, the AP was added according to the desired formulation and the mixture was again stirred until a uniform consistency was achieved. Without degassing, the propellant was pressed into a straw mould which has 70mm length and 5mm diameter. There were 2 main reasons for choosing these dimensions. Firstly, to minimize the pressure and temperature increase in the strand burner combustion chamber during testing. Depending on the composition of mixture, combustion of 2.54 cm (1 inch) strand could increase as much as 10-20% pressure inside the burner [2]. Secondly, this small size reduces material cost, handling and hazardous material. Each of 100 grams of mixtures can produce approximately 27 strands of propellants. The length of the strand burnt is the important parameter to be measured for burning rate calculation, while the size and shape of the strand is less significant [2]. The strands were then transferred to the oven and cured at 64˚C for 5 days. The strands were visually inspected and were rejected if it was showing crack, porous or irregular shape. A cross-sectional view of the propellant was observed under SEM photographs as shown in Fig. 1 in order to investigate the structure of propellant matrix.



1(a)



1(b)

Fig. 1: SEM images of propellant p80 (a) 100X magnifies and (b) 1000X magnifies

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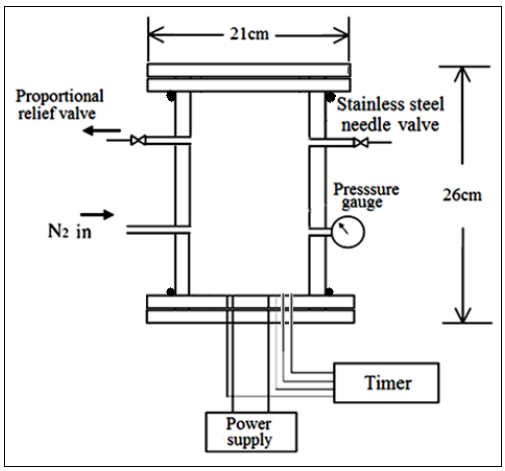
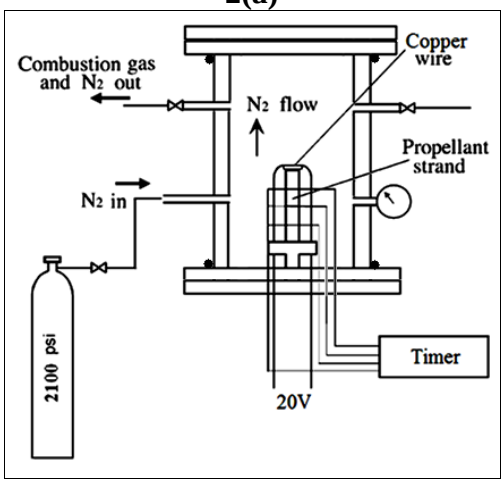
Burning Rate Measurement

The burning rate measurement was carried out with a strand burner which was pressurized using nitrogen gas. The strand burner was designed to handle test pressures up to 38atm (550 psi). The body, flange and both end cap are made of low carbon steel. The 23 cm long cylinder has an inner diameter of 10 cm and an outer diameter of 13 cm, offering a wall thickness of 1.5 cm thickness. Each end cap is 1.5 cm thick, making the overall length of the burner 26 cm as shown in Fig. 2(a). Both end caps are square with side length of 21 cm. The propellant strand was fixed to the end cap using strand holder made of 5mm low carbon steel nut. Nitrogen and combustion products escape to the atmosphere via a stainless steel proportional relief valve as shown in Fig. 2(b).



2(a)



2(b)

Fig. 2: The 38atm strand burner facilities with (a) assembly view and (b) schematic diagram.

To measure the burning rate, the technique used was known as Wire Cutting Technique. Three small holes were accurately placed along the strand length using needle. An igniter and two fuse wires were passed through these holes and connected to a power supply and electronic timer respectively. All wires were of the same type of 38 S.W.G. tinned copper wire with 0.152mm thickness; this is the same type of igniter wire used by Rodolphe *et al.* [2]. The strand is mounted vertically and is ignited at the top end using electrical current. The burning rate was measured for several combustion pressures ranging from 1 to 31atm. It was determined from the period it took for both fuses separated at a distance of 50mm apart to cut-off as shown in Fig. 3.

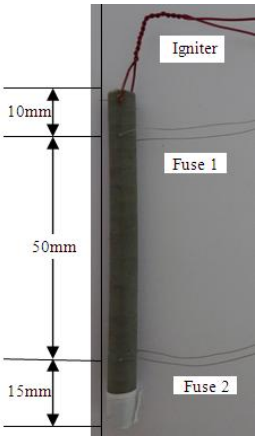


Fig. 3: Set up of propellant strand for burning rate test

Both ends were left with 10mm distance to avoid extinction transient. Four strands were burnt to establish the burning rate at each combustion chamber pressure and repeatability of the burning rates was observed within 5% and is acceptable according to Jayaraman et *al.* [15].

RESULTS AND DISCUSSION

The burning rate tests at ambient pressure have been conducted and from the data collected, a graph of burning rate versus O/F ratio has been plotted as shown in Fig. 4. To further investigate the effect of pressure, four sets of propellant compositions were tested at various pressures and data collected was plotted as shown in Figs. 5 and 6.

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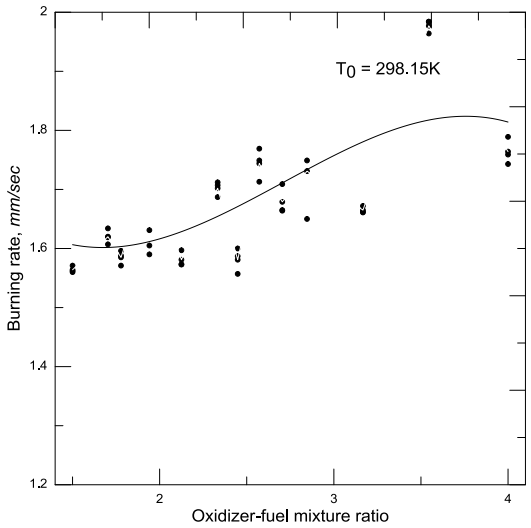

Fig. 4: Burning rate at ambient pressure

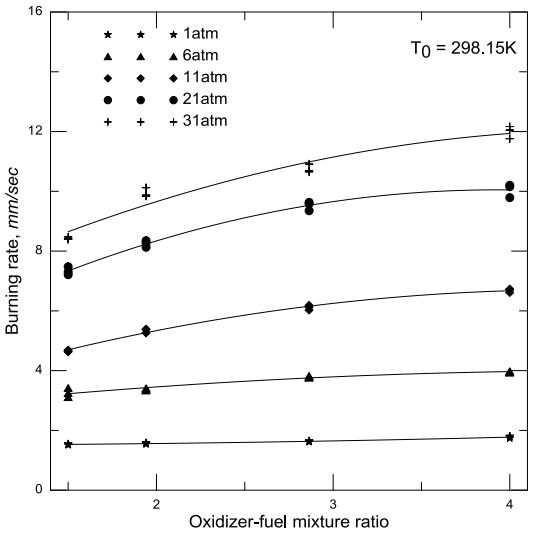

Fig. 5: Burning rate-O/F mixture ratio relationship

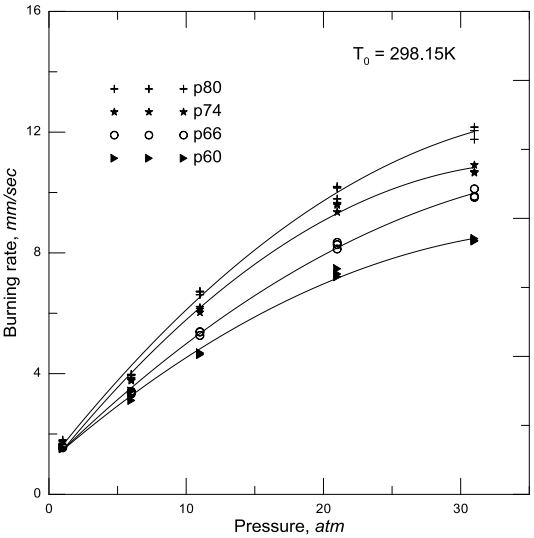

Fig. 6: Burning rate-pressure relationship

Fig. 4 shows that at atmospheric pressure, increasing the O/F ratio will increase the burning rate of the propellant and this has been mentioned by Steinz [16]. However close examination of Fig. 5 shows that the rate of increasing of the burning rate with the increase of O/F ratio is very small at low combustion pressure. This is evident when considering doubling O/F ratio from 1.941 to 4.0 only increases the burning rate by 9.6%. This observation was found in all measurement at constant chamber pressures less than 11atm. For chamber pressures greater than 11atm, it was observed that the burning rate increases significantly with the increase of O/F ratio. This is evident from Fig. 6 where at 31atm, doubling the O/F ratio from 1.941 to 4.0 will increase the burning rate by ±20%.

CONCLUSIONS

The results from the burning rate test shows that:

1. Burning rate increased with the increase of O/F ratio. The same result is also shown from the previous study by Jawalkar [17], which shows that, increasing the solid propellant loading which means the Al and AP, will lead to increase in burning rate.
2. Increasing pressure will increase the burning rate. Compared to the burning rate at ambient pressure, at pressure 21atm, the burning rate increase is five times.

ACKNOWLEDGEMENT

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